ABSOLUTE EFFICIENCY OF ELECTROSTATIC PRECIPITATION FOR COLLECTION OF SILICEOUS DUST

A THESIS

Presented to

the Faculty of the Division of Graduate Studies

Georgia School of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Mechanical Engineering

by

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September 1950

ABSOLUTE EFFICIENCY OF ELECTROSTATIC PRECIPITATION

FOR COLLECTION OF SILICEOUS DUST

Approved:

Date Approved by Chairman Sept 5, 1950

ACKNOWLEDGEMENTS

I would like to express my appreciation to Doctor J. M. Dalla Valle for suggesting the problem for study, and also for his interest and aid, without which the completion of the work would have been much more difficult. My sincere gratitude is also extended to Professor A. D. Holland, Professor W. A. Hinton, Mr. T. D. Sangster and Miss Frances Kaiser for their kind assistance and encouragement.

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PURPOSE OF THE STUDY

It is the purpose of this study to examine the effect of air velocity and dust concentration on electrostatic precipitation by the technique of actually counting the dust particles precipitated.

It is evident that a number of variables may influence the efficiency of an electrostatic precipitator. Some of the more important ones are: the velocity of the air and particle through the collector plates, the length of the collector plates, the amount of charge taken by the particle, the size of the particle, the dielectric constant of the particle, the particle concentration, and the humidity of the surrounding air.

Efficiencies of electrostatic precipitators have been calculated many times and may be done by one of the following three methods[1]: (1) weight methods; (2) a discoloration method developed by the National Bureau of of Standards[2]; and (3) a count of the particles.

Weight methods are usually ruled out as it is difficult to secure sufficient samples for weighing.

Dirt collection efficiencies are generally determined by the discoloration method. This method consists of

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[1] F. B. Rowley and R. C. Jordan, "A Comparison of the Weight, Particle Count and Discoloration Methods of Testing Air Filters," A.S.H.V.E. Transactions, Vol. 47, 1941, p. 29.

[2] R. S. Dill, "A Test Method for Air Filters," A.S.H.V.E. Transactions, Vol. 44, 1938, p. 379.

drawing samples of air, both before and after the precipitator, through a special filter paper. The arrangement is such that the areas of the exposed paper may be varied so that the upstream and downstream air samples cause equal blackness or discoloration, the discoloration being compared photometrically by reflected light to secure as accurate a test as possible. The ratios between the discolored areas indicate the efficiency of the precipitator. Atmospheric air is used and efficiencies above 90% are claimed.

Two questions should be borne in mind with reference to the discoloration method[3]; (1) can the efficiency of the filter disks be regarded as constant for dusts collected on both sides of the precipitator, and (2) are the color properties of the dusts sampled the same. If during a sampling period, the downstream filter becomes relatively more efficient and fewer particles pass through it, the indicated result would be lower than the precipitator's true efficiency. In regards to the second question, it is obvious that color is a function of particle size, thus making it difficult to see how a discoloration test can yield reliable results.

If we define efficiency of a precipitator as the extent to which small particles are removed from an air

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[3] J. M. Dalla Valle, The Industrial Environment and Its Control (New York and London: Pitman Publishing Corporation, 1948), p. 184.

stream, then, whatever the method used, its characteristics must be determined in terms of absolute particle count.

DEVELOPMENT OF ELECTROSTATIC PRECIPITATION

The effect of an electric discharge on particles suspended in a gas was first observed in 1824 by Hohlfeld,[4] a teacher at Leipzig, Germany. He noted that if an electrically charged wire were hung in a smoke filled bottle, the smoke would clear rapidly, being deposited on the inside of the bottle.

In 1885, Sir Oliver Lodge[5] attempted to use electrostatic precipitation to remove lead fumes at the Dee Bank Lead Works in Wales. Commercially, the experiment proved unsuccessful, but it did lead to the first patents on electrostatic precipitators.

The first successful application of electrostatic precipitation was made by Doctor F. G. Cottrell[6] in 1906. His device, known as the Cottrell Precipitator,[7] has been used in recovering valuable dusts and in precipitating fly ash from the flue gase in large power plants. However, the Cottrell Precipitator requires a potential ranging from

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4 The Air-Maze Corporation, "Electrostatic Precipitation of Atmospheric Dust, a Condensed and Simplified Explanation," (Cleveland), p. 1.

5 Loc. cit.

6 Ibid., p. 2.

7 K. H. Cree, "Cottrell Electrical Precipitation as Applied to the Manufactured Gas Industry," Americal Gas Journal, 162:27-30, March, 1945.

30,000 to 100,000 volts and produces large and injurous amounts of ozone, making it undesirable for air-conditioning work. The Cottrell Precipitator, in its simplest form, consists of two sets of electrodes of such shape as to facilitate an electrical discharge from their surface. Its elements are: the precipitator, a rotary rectifier, and a transformer. There are two types, the pipe type and the plate type. In the pipe type the potential is applied between a metal cylinder and an axial wire. In the plate type the potential is applied between a series of parallel plates, which have alternate positive and negative charges. The plate type might have electrodes of corrugated steel, reinforced concrete slabs, rod curtains, hollow electrodes with tulip shaped appendages on the surface, or perforated steel plates. Each type has certain advantages.

For use in ventilating work the disadvantages of the Cottrell Precipitator are:[8]

(1) DC voltages of from 30,000 to 100,000 and an appreciable current is required.

(2) The space required is large, both for the precipitator proper as well as the high-voltage transformer and rectifier.

(3) The corona discharge generates so much ozone that the cleaned air, although free of dust, is too irritating to the nose and throat to be used for ventilation.

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[8] G. W. Penney "A New Electrostatic Precipitator," Electrical Engineering, 56:159-163, January, 1937.

(4) First cost and maintenance are both high as compared to the other types of cleaning equipment.

In 1913, W. A. Schmidt[9] of the Western Precipitation Company patented a design for a two-stage precipitator where the dust particles are charged in the first stage and collected in the second stage. This idea has been adopted and is used extensively in today's modern precipitators.

In 1933, the Westinghouse Electric Corporation[10] developed a two-stage electrostatic precipitator with very low ozone generation which was suitable for ventilating work. This precipitator was registered under the trade name "Precipitron," and it was with a demonstration model of the "Precipitron" that this study was made. It consists essentially of three elements: the ionizer, the collector cell, and the power pack. The ionizer consists of No. 33 tungsten wires spaced parallel between grounded metal tubes and charged with a positive 13000 DC voltage. The collector cell consists of parallel aluminum plates with alternate plates grounded and charged with a positive 6000 DC voltage. The power pack consists of a voltage doubling circuit made up of two rectifier tubes, a step-up transformer, and a capacitor. This converts the 115 volt, single

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9 The Air-Maze Corporation, <u>loc</u>. <u>cit</u>.

10 C. H. McWhirter, R. P. Posey, "Electrostatic Air Cleaning in the Textile Industry," A paper presented to the A.I.E.E. Southern District Meeting in Birmingham, Alabama, November, 1948.

phase, AC supply to the required 13000 and 6000 DC voltages.

As used in ventilating systems today, electrostatic precipitators are often installed in rows or banks. In automatic cleaning devices, the grounded plates are made to revolve through a bath of oil where the precipitated dust is washed off. A thin coat of oil on the plates will help hold the dust while the precipitator is in operation. However, in many cases the collector plates are cleaned by a fine water spray, then sprayed with the oil.

Electrostatic precipitators are most efficient in the collection of very small particles. Particles above ten microns (one micron = 10^{-4} centimeters) are readily removed by various means, such as centrifugal devices, simple filters, air washers, or by viscous coated devices which depend on impinging the particles onto the coated surfaces. In many cases the dust particles are only a fraction of a micron in diameter and approach the resolving power of an ordinary microscope.

THEORY OF ELECTROSTATIC PRECIPITATION

The principle involved in electrostatic precipitation is the old one of "like charges repel and unlike charges attract." A positively charged particle is repelled by a positively charged plate and attracted by a negatively charged one.

When a high voltage is applied to the ionizing wire in the ionizing section of a precipitator, a bluish discharge called corona is formed. This discharge is actually a stream of electrons flowing between the two electrodes and will cause any air molecules or atoms flowing past to become charged. These charged air molecules are called "ions." For the most part, positively charged ions are created, although some negatively charged ions are formed. The total number of ions created runs into billions; thus making it inevitable that some of the ions will collide with any dust particle entering the ionizing section and attach themselves to the particle, imparting to it the ions electrical charge. It can be shown that a greater production of ions is attained if the ionizing wire is of negative polarity, but this creates a larger amount of ozone. Therefore, the ionizing wires of commercial precipitators are positively charged.

When a dust particle has received its charge and enters the collector section, it is repulsed by the plates having a like charge and attracted by the plates having an unlike charge.

By Stokes' law, the resistance encountered by a particle moving with streamline motion in an electric field is:[11]

$$R = Kuvd \qquad \text{Eq. (1)}$$

where: R is the resistance
v is the velocity of the particle
d is the diameter of the particle
u is the viscosity of the air
K is a constant (3π for spheres)

If the motion of the particle is steady, this resistance is countered by, and equal to, the force of the electric field, such that

$$R = Kuvd = Ene \qquad \text{Eq. (2)}$$

where: E is the voltage gradient
n is the number of unit charges
e is the unit charge

or,

$$v = \frac{Ene}{Kud} \qquad \text{Eq. (3)}$$

From this equation it can be seen the velocity is directly propotional to the strength of the field and the charge on the particle, and inversely propotional to the diameter. If the path of the charged particle is desired, we have

$$v = \frac{dx}{dt} \text{ and } E = \frac{V}{x}$$

where: x is a linear coordinate
V is the voltage applied
t is the time

[11] Dalla Valle, *op. cit.*, p. 182.

therefore, $\frac{dx}{dt} = \frac{ne}{Kud} \cdot \frac{V}{x}$ Eq. (4)

On integrating Eq. (4) from x = o to x = x, and t = o to t = t, we obtain

$$\frac{x^2}{2} = \frac{neV}{Kud} \cdot t$$

or, $Kudx^2 = 2neVt$ Eq. (5)

If the velocity of the air and the particle moving along a y coordinate is v', then $y = v' t$ so that at the time t, from an initial position and time $t = 0$,

$$Kudx^2 = 2neV \cdot \frac{y}{v}$$

or, $y = \frac{Kudv}{2neV} \cdot x^2$ Eq. (6)

This equation is that of a parabola; thus it can be seen that a charged dust particle will follow a parabolic path in the collector section of a precipitator.

Providing the charge on the particle (ne) remains constant, Eq. (6) can be used in determining the dimensions of the collector plates. Actually, the charge taken by the dust particle is a function of the time the particle remains in the electrostatic field. This charge may be calculated from an equation originated by Pauthenier as follows:

$$(ne) = \left[1-2\left(\frac{ko-1}{ko+2}\right)\right] \cdot \pi\frac{d^2ti}{4}\left(\frac{1}{\frac{1+\pi ti}{E}}\right) \quad \text{Eq. (7)}$$

where: ko is the dielectric constant of the particle
i is the current density

When the particle is a sphere, the bracketed expression is equal to three. Also, when the time t, is very large, the last term in parentheses approaches unity.

In the above equations, x and d are measured in centimeters, t in seconds, and E and i in electrostatic units.

In commercial precipitators, as built for ventilating work, the collector plates are of length sufficient to collect particles ranging from 1/10 to 1/50 of a micron. Velocities used are those normally used in ventilating filters and range from 300 to 375 feet per minute. Voltage gradients across collector plates are adjusted to eliminate excessive arcing. The spacing of collector plates in precipitators depends upon the voltage. To assure maximum attraction between the charged particles and the collector plates, the voltage gradient used is usually that gradient reached just before spark-over occurs.

The behavior of charged dust particles in the collector section of a precipitator is shown in Figure 1.

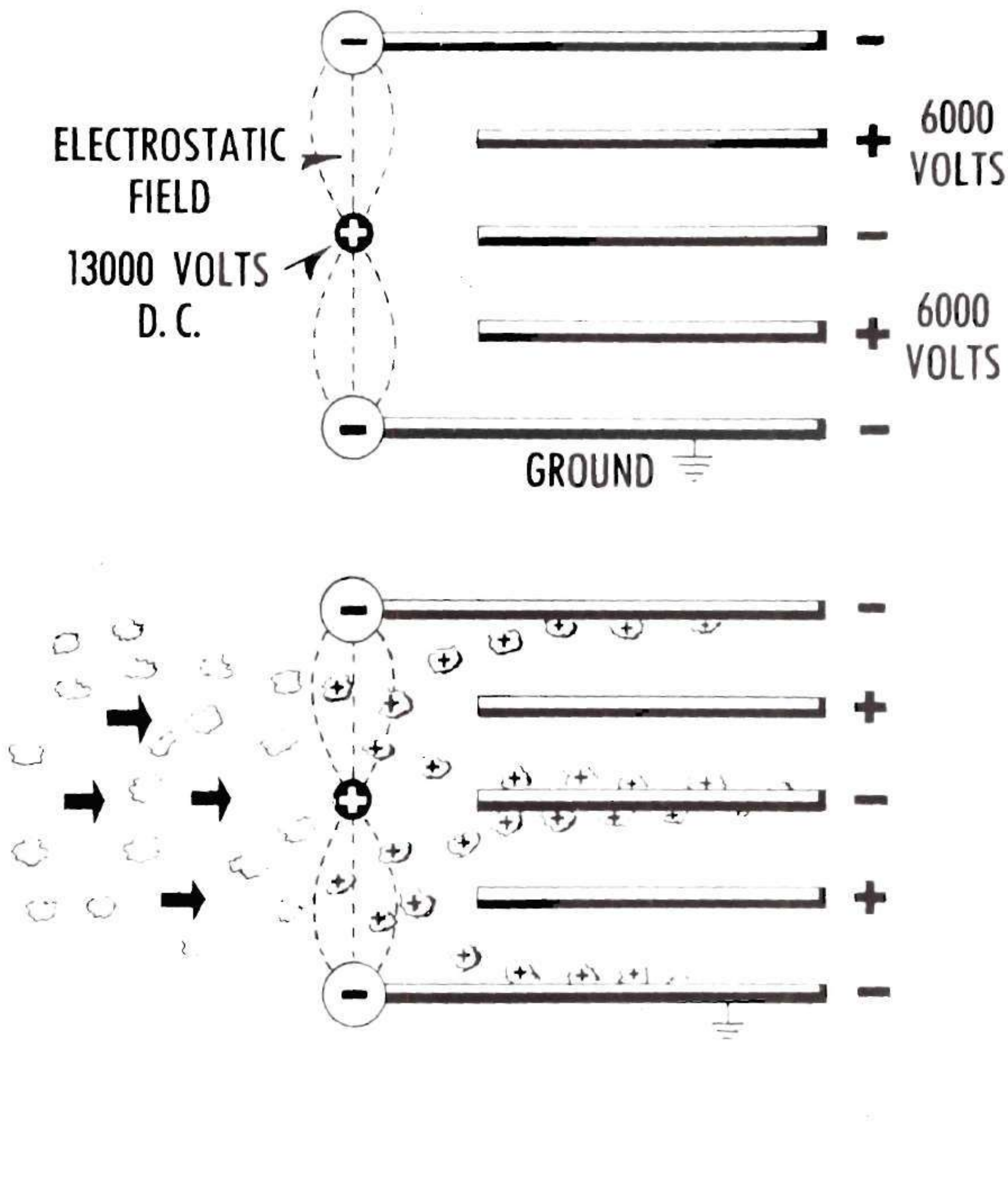

ELECTROSTATIC FIELD
13000 VOLTS D. C.
6000 VOLTS
6000 VOLTS
GROUND

FIGURE 1

APPARATUS

<u>The Precipitator Unit</u>: The precipitator used in this study was manufactured by the Westinghouse Electric Corporation and was built for demonstration purposes. The two collector cells, which were installed in a rectangular duct about 6 feet long, were each 8 inches wide, 18 inches high, and 23 inches deep in the direction of the air flow. The plates were made of aluminum and arranged in a horizontal position. They were spaced on 5/16 inch centers and charged with 6000 volts DC, which produced a voltage gradient of 19,200 volts per inch. The ionizing section of each cell consisted of two strands of No. 33 tungsten wire, insulated from the rest of the cell, and mounted vertically between grounded struts. The wires were charged with 13,000 volts DC. By the discoloration test previously described, each cell was claimed to be 90% efficient at 300 cubic feet per minute.

Attached to the forward end of the rectangular duct by a plywood hood was a 9 inch No. 1½ Sirroco centrifugal blower type fan. The fan was driven by a General Electric 3 phase, 220 volt, ½ h.p. motor with an R.P.M. rating of 960/1140. To control the air flow, a damper was installed on the fan intake and calibrated at five positions to give the following readings:

Damper Position	Air Flow
A	220.1 cu. ft./min.
B	419.5 cu. ft./min.
C	588.4 cu. ft./min.
D	824.1 cu. ft./min.
E	1091.2 cu. ft./min.

To measure the air through the precipitator at the five damper positions a Alno Velometer Type 3002 was used. The standard procedure for measuring air flow in a duct was followed. A dimensioned sketch of the duct and precipitator unit is shown in Figure 2 and a photograph in Figure 3.

To transform and rectify the 115 volt AC supply, a Westinghouse self-contained unit called the power pack was used. A diagram of the electrical circuit is shown in Figure 4.

The Dust Feed Apparatus: The dust feed was artificial and automatic. Air, reduced to a very low pressure by a pressure regulating valve, was made to blow into a small cylinder and onto the top of a spiral grooved piston. The piston was continuously being lowered by a small 2 watt, one R.P.M., and 115 volt synchronous motor. The air, following the spiral grooves on the piston, blew over the top of the dust in the bottom of the cylinder and carried it out through a small hole drilled through the center of the piston and piston rod. Various piston speeds could be attained by changing gear ratios on the motor, and any reasonable air pressure could be maintained by the pressure regulating valve. Thus, by changing the piston speed and the air pressure, practically any dust concentration could be maintained. The motor and dust filled cylinder were mounted on a small board 6 inches wide and 15 inches high. To measure the air pressure a small mercury-filled U tube was used. A photograph of the dust-feed apparatus is shown in Figure 5, but the path followed by the air and dust can be seen better in Figure 6. To insure thorough mixing of the dust in the air stream, the dust from the cylinder was introduced into the precipitator at the fan intake.

The dust used throughout the study was Santocel, a form of silicon oxide, and a product of the Monsanto Chemical Company. Its size was less than 3 microns.

Air Sampling Apparatus: In order to calculate the precipitator efficiency, it was necessary that the air be sampled for a period of time both before and after the collector plates. To do this, a 1/10 h.p. centrifugal type vacuum pump pulled the sampling air through two tubes located before and after the plates and thorough two midget impingers filled with 20 cubic centimeters of distilled water. Also in each line were two wet-test or gas meters to measure the amount of air sampled. The arrangement of the air sampling apparatus can be seen in Figure 3 and Figure 6. The midget impingers were designed for a sampling rate of

1/10 cubic foot of air per minute, and this rate was held as close as possible by valves located on the lines to the vacuum pump.

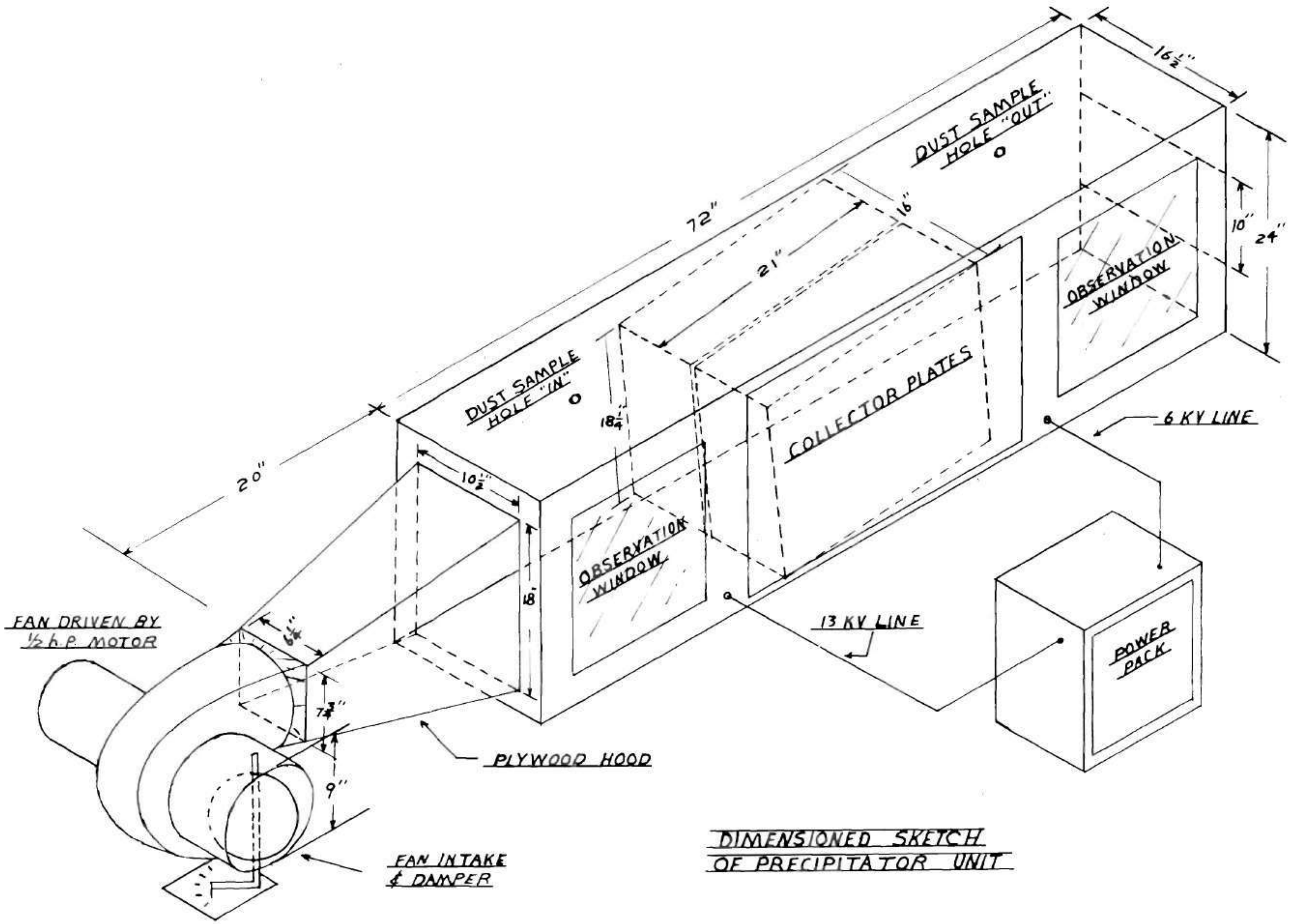

72"
16½"
DUST SAMPLE HOLE "OUT"
10"
24"
16"
21"
OBSERVATION WINDOW
DUST SAMPLE HOLE "IN"
18¼"
COLLECTOR PLATES
6 KV LINE
20"
10½"
OBSERVATION WINDOW
18"
FAN DRIVEN BY ½ h.p. MOTOR
6¼"
13 KV LINE
POWER PACK
7¾"
PLYWOOD HOOD
9"
DIMENSIONED SKETCH OF PRECIPITATOR UNIT
FAN INTAKE & DAMPER

FIGURE 2

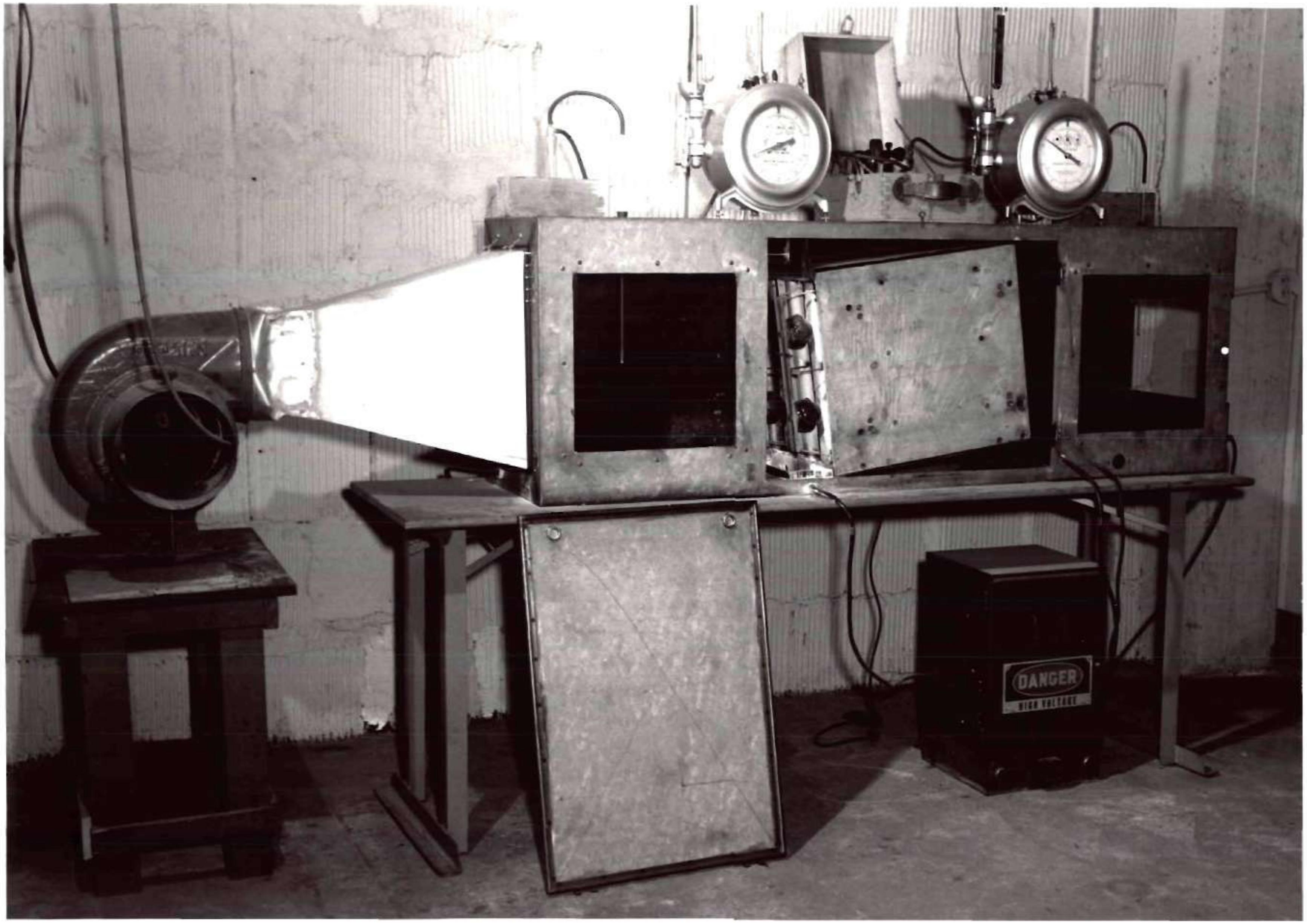
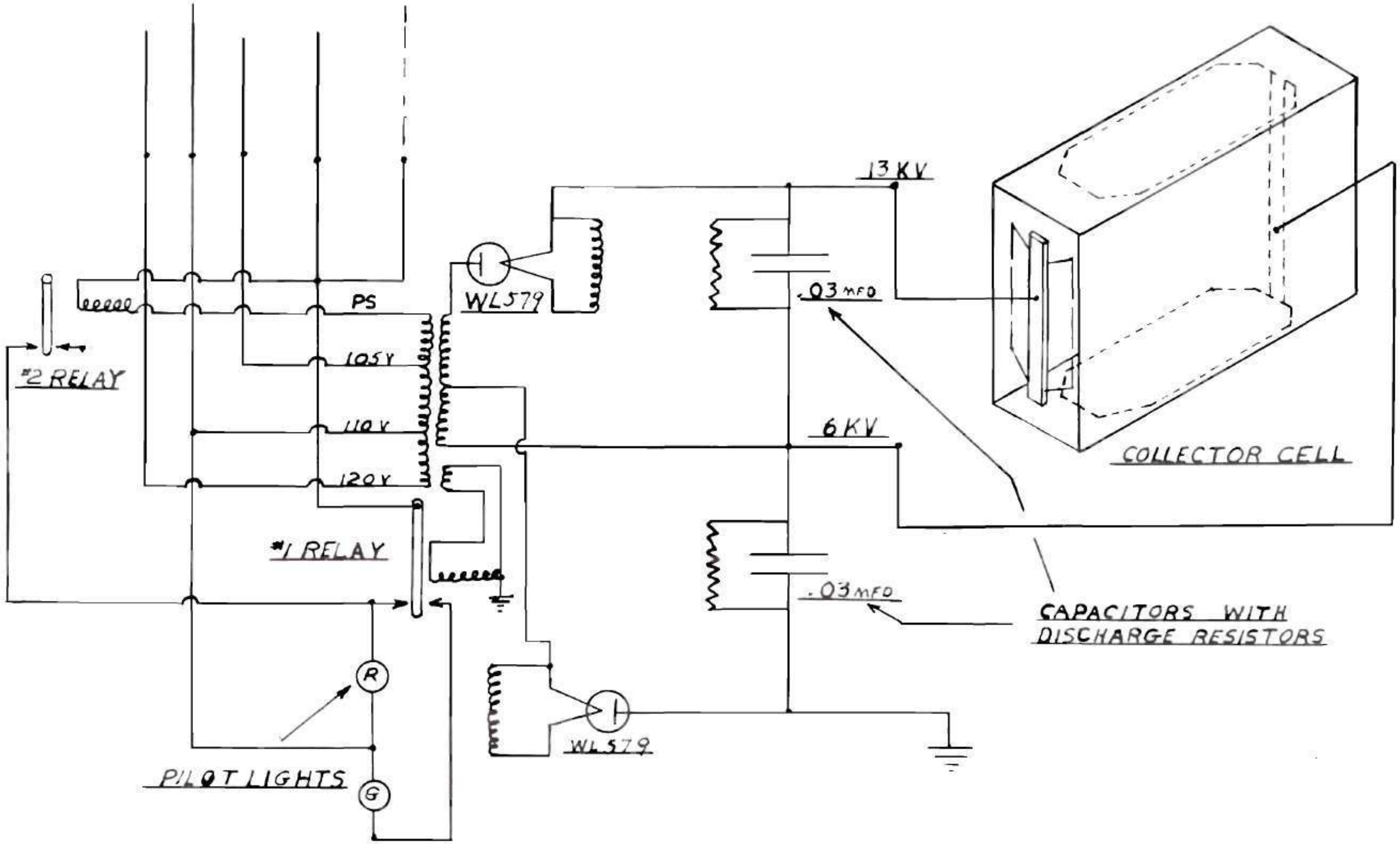


FIGURE 3



SCHEMATIC ELECTRICAL DIAGRAM

FIGURE 4

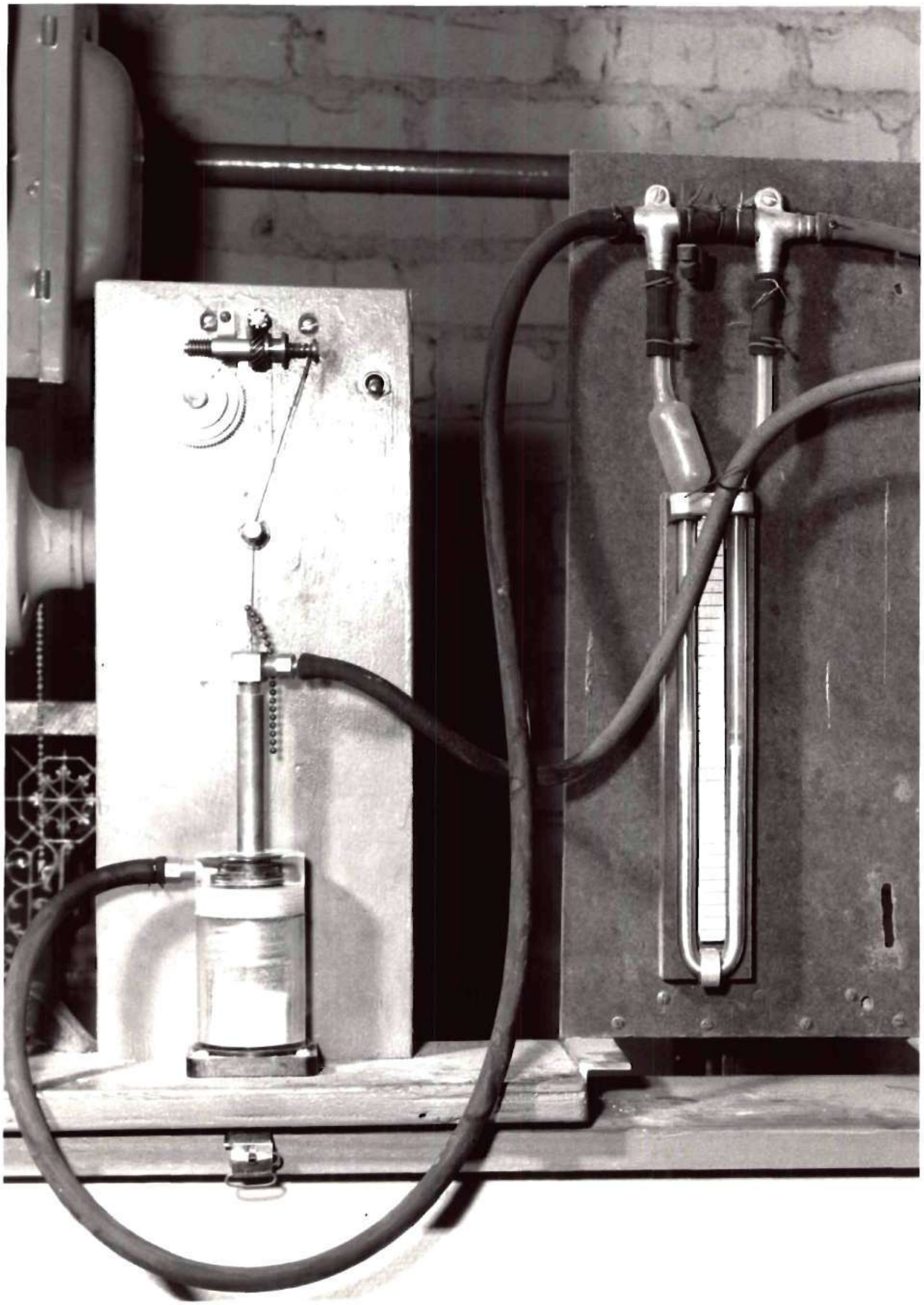
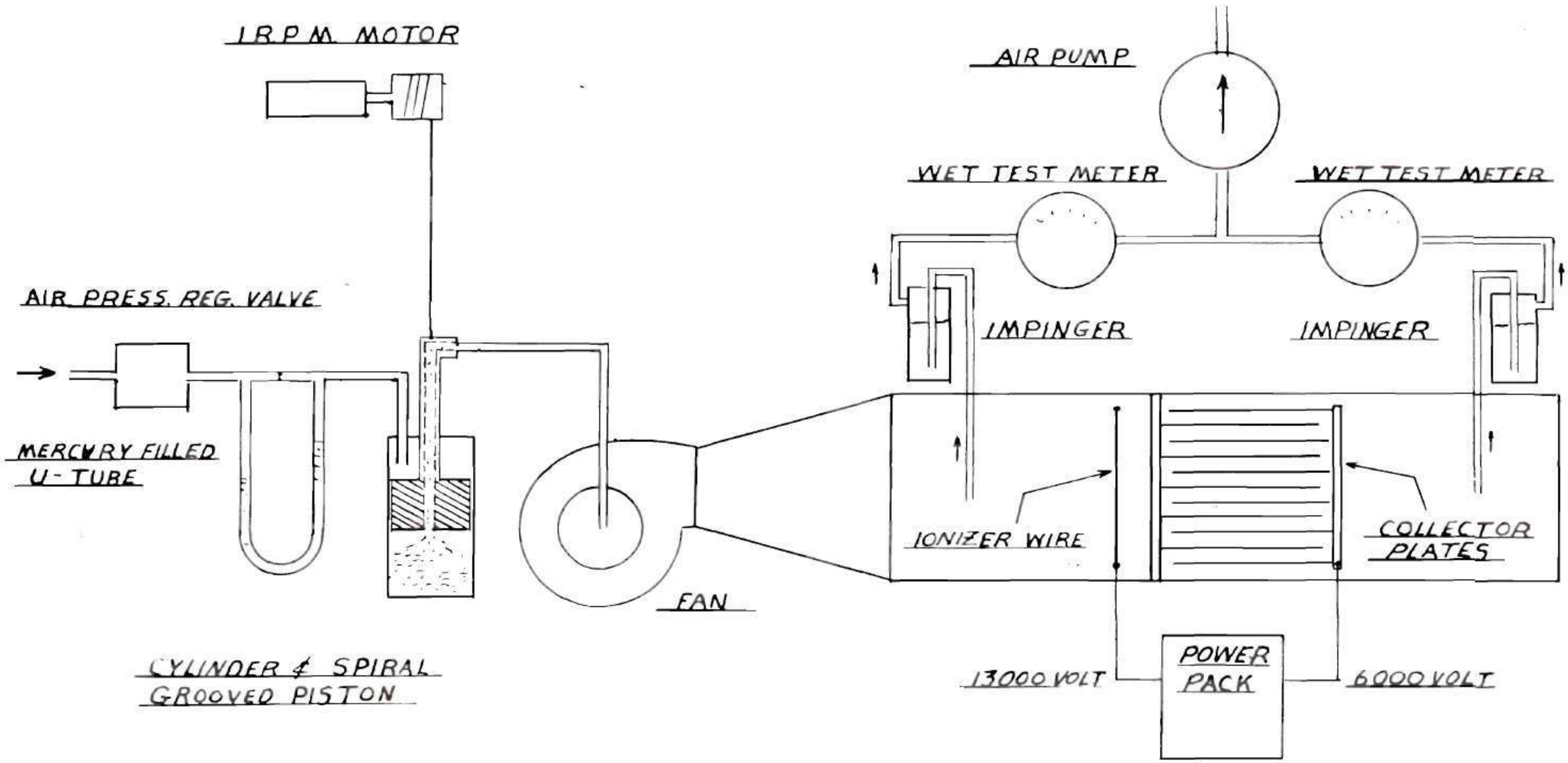


FIGURE 5



SCHEMATIC DIAGRAM OF LAYOUT

FIGURE 6

METHOD USED TO TAKE DATA

Three different weights of dust were used. Each weight represented an average of the weight of dust used during any one set of runs, ie, the weight of dust used for any one of the three efficiency curves was taken to be constant. Due to the fact that these tests were made at five different and increasing air volumes, the dust concentration per cubic foot of air decreased when the air flow was increased.

For each damper position on the fan (A,B,C,D,E), two runs were made and the air sampled for each run. The dust captured in the impingers was counted for each run. The efficiency of the precipitator at each damper position was found by averaging the efficiencies of the two runs.

The first set of runs made were those represented by the dust weight W_1, the second set by the dust weight W_2, and the third set by the dust weight W_3. The samples taken for each run were kept in small bottles, which had previously been thoroughly rinsed in distilled water, and were always counted within three days. The impingers were likewise rinsed in distilled water after each run. To avoid confusion, the samples for each set of runs were marked as to which damper position, run one or two, and "in" or "out" to designate whether the sample was taken upstream or downstream from the collector plates.

In order to obtain the desired dust concentrations, it was found necessary to vary the time of each set of runs. The times used were as follows: three minutes for the runs made using dust weight W_1, six minutes for the runs made using dust weight W_2, and nine minutes for the runs using dust weight W_3.

METHOD USED TO COUNT THE PARTICLES AND CALCULATE THE EFFICIENCY

The light-field[12] method was used to count the number of particles captured from the air stream by the impingers. The microscopic equipment included a Bausch and Lomb microscope, a 10 power ocular, a No. 802 Whipple micrometer disk, and a standard microscope lamp.

The counting cell used was a standard Sedgwick-Rafter chamber. This type of chamber is one millimeter in depth and will hold exactly one cubic centimeter of water. One cell was prepared from each sample and five fields, one centrally located, and each of the others in one of the four corners of the chamber were counted. Counts made with a Sedgwick-Rafter chamber are sometimes made while lowering and raising the lens system so as to focus throughout the depth of the cell, but in this case the chamber was allowed to sit for a few minutes and only the particles which settled to the bottom of the chamber were counted.

Dust particles which might be on the Whipple disk cannot be distinguished from particles in the counting chamber. For this reason, the Whipple disk was thoroughly cleaned before any count was made. However, once the

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[12] Philip Drinker and Theodore Hatch, Industrial Dust (New York and London: McGraw Hill Book Company, Inc., 1936), p. 117.

count was started everything observed was counted.

Prior to any counting, the Whipple disk was calibrated as follows:

Each square on the disk = 0.1 mm. on a side

Therefore, area of one square = 0.01 $mm.^2$

In any one field 20 squares on the disk were counted, or in the five fields 100 squares were counted, therefore:

Total area counted = (100)(0.01) = 1.0 $mm.^2$

Since the chamber was also 1.0 mm. deep, the total volume counted was;

Total Volume Counted = (1.0 mm^2)(1.0 mm) = 1.0 $mm.^3$

The volume of the sample taken was 20 cc. or 20,000 $mm.^3$ Therefore, the total dust count was:

$$\text{Total Count} = (\text{Count}/mm^3)(20000\ mm.^3)$$

To determine the particle count per cubic foot of air, it was necessary to divide the total count by the cubic feet of air sampled, such that

$$\text{Count}/ft.^3 = (20{,}000)\left(\frac{\text{Count}/mm^3}{\text{Cu. ft. of air sampled}}\right)$$

As mentioned previously, two runs and therefore two counts were made at each position of the fan damper. The precipitator efficiency for any single run was calculated from the following:

$$E = \frac{Ci - Co}{Ci} \cdot 100$$

where: E is the precipitator efficiency in per cent

Ci is the particle count per cubic foot of air sampled flowing into the precipitator

Co is the particle count per cubic foot of air sampled flowing out of the precipitator

The precipitator efficiency used in plotting the efficiency curves was an average of two efficiencies, or

$$E_{avg.} = \frac{E_1 + E_2}{2}$$

where: $E_{avg.}$ is the average efficiency.

E_1 is the efficiency of the first run.

E_2 is the efficiency of the second run.

As a matter of interest, the dust concentration in milligrams per cubic foot of air flowing through the precipitator was calculated by the following:

$$\text{milligrams}/\text{ft}^3 = \frac{\text{weight of dust used}}{\text{total air volume}}$$

DISCUSSION

The efficiencies, weight concentrations, and particle counts are tabulated in Tables I, II, and III in the Appendix. From the Tables the efficiency curves shown in Figure 7 were drawn. Each of the curves are marked W_1, W_2, or W_3 according to the weight of dust used. Plotted above the efficiency curves in Figure 7 are a corresponding set of weight concentration curves. From these the dust weight in milligrams per cubic foot of air can be read for any given air volume.

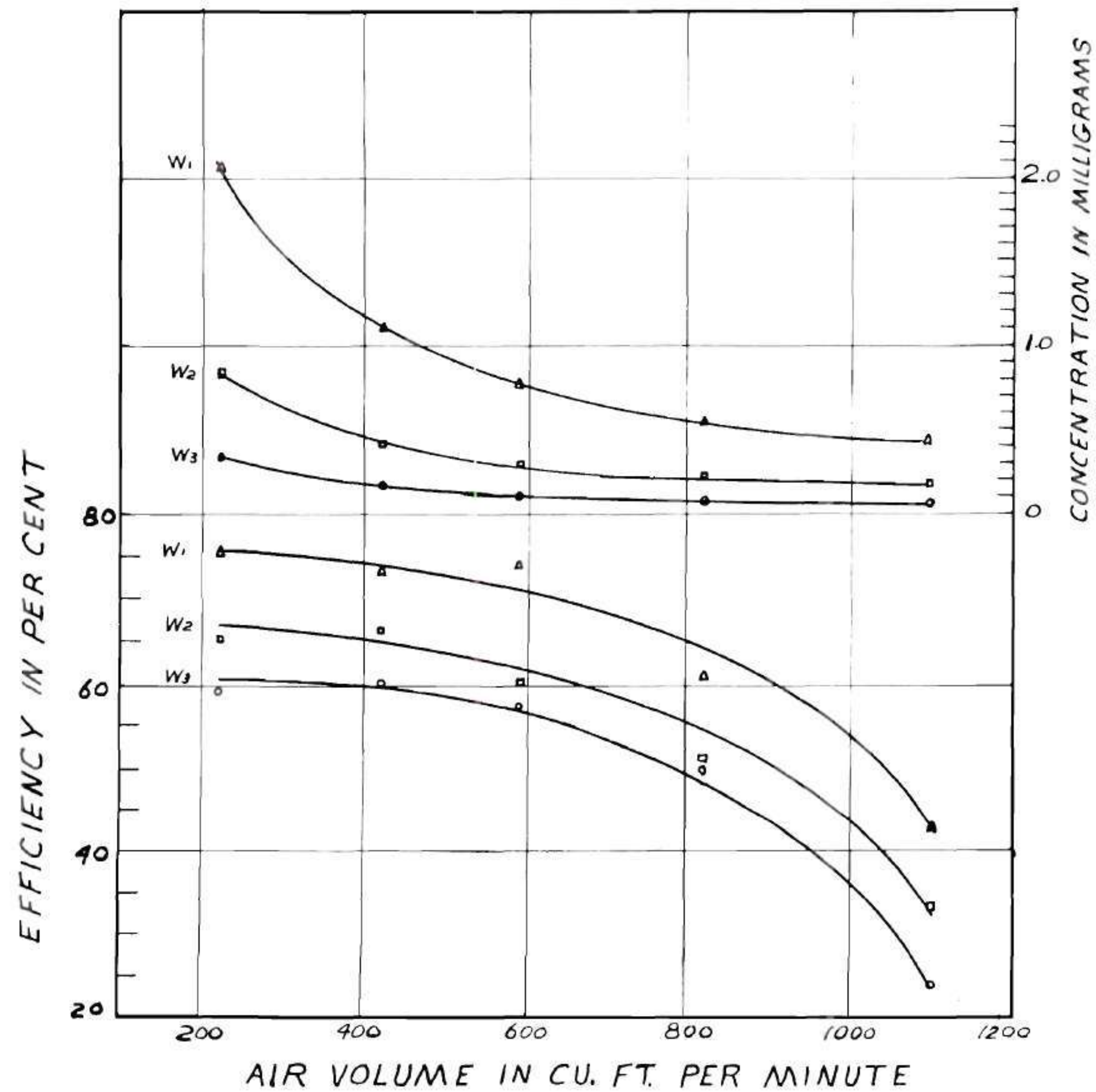
The efficiency curves illustrate vividly the rapid decrease of precipitator efficiency with increasing air volume regardless of the dust concentration. Each curve also seems to fall off with identical rates. This result was, to some extent, expected. However, it is rather difficult to explain the pointed fact that the higher dust concentrations also had the higher efficiencies. The counting of small dust particles through a microscope is a tedious and difficult proposition. Also, dust on the lens of the microscope would introduce errors into the counts.

In these tests, the air stream through the precipitator was sampled through glass tubes located on both sides of the collector plates. It is conceivable that, due to their momentum, some of the heavier particles did not make the 90 degree turn necessary and therefore were not sampled.

However, as far as is known by the writer, there has not yet been developed an apparatus which will accurately sample a stream of moving air.

As dust collects on the plates of a precipitator, it is possible that the intensity of the electric field increases. If this is true, more dust would be precipitated when the plates are heavily coated. If the field intensity increased too much, arcing would probably occur and knock the dust from the plates back into the air stream.

It was noticed that the precipitator collected a large percentage of the dust on the grounded electrodes in the ionizing section and the rest on the first two or three inches of the plates. This indicates the plates might be longer than actually necessary for some types of dust. The extent to which the ionizing section became coated can be seen from Figure 8, which shows one cell cleaned and one uncleaned. It was also noticed that the positively charged plates collected nearly as much dust as the negatively grounded plates, indicating that a number of negative ions must be created in the ionizing section.



PRECIPITATOR EFFICIENCY CURVES

FIGURE 7

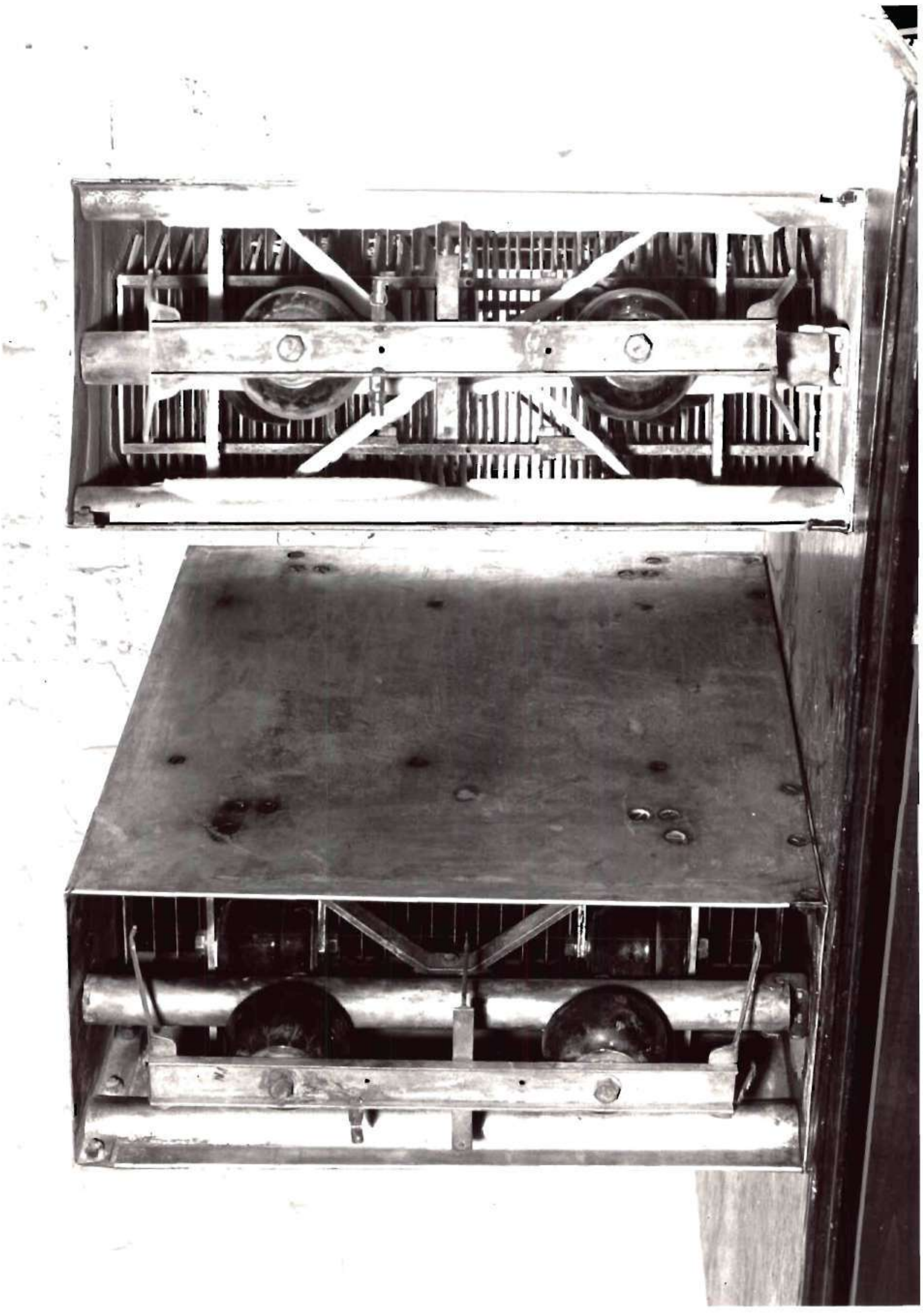


FIGURE 8

CONCLUSIONS

The efficiencies found in this study do not even approximate the efficiencies claimed by the manufacturers of electrostatic precipitators. The general efficiency rating in the industry, using the discoloration test, is 90 per cent at 300 feet per minute and 85 per cent at 375 feet per minute. The maximum efficiency reached in these tests was about 75 per cent.

When a precipitator is tested in industry, usually no artificial dust feed is made, and the test indicates the percentage of dirt removal from atmospheric air. There are many different sizes and kinds of dirt particles suspended in the atmosphere, some of which are easier to precipitate than others. Perhaps a better correlation between these results and the manufacturers claims would have been found if a mixture of dusts had been used.

As can be seen from the efficiency curves and the tables, the efficiency of the precipitator used in this study increased with dust concentration. This phenomenon may be true only within the limits of dust concentration used, and, for the most part, will have to remain unexplained.

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APPENDIX

TABLE I

DATA AND RESULTS FOR W_1 EQUAL 1390 MILLIGRAMS

RUN	VOL. AIR SAMP-IN	VOL. AIR SAMP-OUT	COUNT/MM.^{3} IN	COUNT/MM.^{3} OUT	COUNT/FT.^{3} X10^3-IN	COUNT/FT.^{3} X10^3-OUT	EFFICIENCY
			Damper Position "A"-220.1 Ft.^{3}/Min. milligrams per Ft.^{3}-2.110				
(1)	0.3265	0.3260	907	223	55560	13680	75.4%
(2)	0.3303	0.3272	729	178	44180	10880	75.4%
						Average =	75.4%
			Damper Position "B"-419.5 Ft.^{3}/Min. milligrams per Ft.^{3}-1.104				
(1)	0.3130	0.3085	560	160	35780	10370	71.0%
(2)	0.3233	0.3483	673	173	41630	9934	76.1%
						Average =	73.5%
			Damper Position "C"-588.4 Ft.^{3}/Min. milligrams per Ft.^{3}-0.787				
(1)	0.3300	0.3294	490	123	29700	7460	74.8%
(2)	0.3263	0.3239	437	113	26790	6880	74.3%
						Average =	74.5%
			Damper Position "D"-824.1 Ft.^{3}/Min. milligrams per Ft.^{3}-0.563				
(1)	0.3175	0.3165	352	126	22170	7962	64.1%
(2)	0.3210	0.3202	305	130	19000	8119	57.3%
						Average =	60.7%
			Damper Position "E"-1091.2 Ft.^{3}/Min. milligrams per Ft.^{3}-0.425				
(1)	0.3180	0.3138	223	123	14030	7839	44.1%
(2)	0.3395	0.3397	184	105	10840	6182	42.9%
						Average =	43.5%

TABLE II

DATA AND RESULTS FOR W_2 EQUAL 1083 MILLIGRAMS

RUN	VOL. AIR SAMP-IN	VOL. AIR SAMP-OUT	COUNT/MM.^{3} IN	COUNT/MM.^{3} OUT	COUNT/FT.^{3} X10^3-IN	COUNT/FT.^{3} X10^3-OUT	EFFICIENCY
			Damper Position "A"-220.1 Ft.^{3}/Min. milligrams per Ft.^{3}-0.820				
(1)	0.6060	0.6047	185	74	6106	2447	59.9%
(2)	0.6212	0.6217	155	51	4990	1641	67.1%
						Average =	63.5%
			Damper Position "B"-419.5 Ft.^{3}/Min. milligrams per Ft.^{3}-0.430				
(1)	0.6455	0.6450	161	51	4988	1581	68.3%
(2)	0.6155	0.6118	166	58	5427	1896	65.1%
						Average =	66.7%
			Damper Position "C"-588.4 Ft.^{3}/Min. milligrams per Ft.^{3}-0.307				
(1)	0.5825	0.5788	123	49	4223	1693	59.9%
(2)	0.6030	0.5995	118	46	3914	1535	60.8%
						Average =	60.3%
			Damper Position "D"-824.1 Ft.^{3}/Min. milligrams per Ft.^{3}-0.2195				
(1)	0.6151	0.5985	101	46	3284	1537	53.2%
(2)	0.6053	0.6022	109	52	3602	1727	52.1%
						Average =	52.6%
			Damper Position "E"-1091.2 Ft.^{3}/Min. milligrams per Ft.^{3}-0.166				
(1)	0.5986	0.5996	80	54	2673	1081	32.6%
(2)	0.5951	0.6100	92	65	3092	2131	31.1%
						Average =	31.8%

TABLE III

DATA AND RESULTS FOR W_3 EQUAL 663 MILLIGRAMS

RUN	VOL. AIR SAMP-IN	VOL. AIR SAMP-OUT	COUNT/MM.^{3} IN	COUNT/MM.^{3} OUT	COUNT/FT.^{3} X10^3-IN	COUNT/FT.^{3} X10^3-OUT	EFFICIENCY
			Damper Position "A"-220.1Ft.^{3}/Min. milligrams per Ft.^{3}-0.335				
(1)	0.9312	0.9365	172	70	3694	1495	59.5%
(2)	1.0500	1.0520	166	71	3162	1350	57.3%
						Average =	58.4%
			Damper Position "B"-419.5Ft.^{3}/Min. milligrams per Ft.^{3}-0.1755				
(1)	0.9735	0.9765	126	51	2589	1045	59.6%
(2)	0.9523	0.9548	140	56	2940	1173	60.1%
						Average =	59.9%
			Damper Position "C"-588.4Ft.^{3}/Min. milligrams per Ft.^{3}-0.125				
(1)	0.9225	0.9300	132	58	2862	1247	56.4%
(2)	0.9235	0.9090	153	63	3313	1386	58.2%
						Average =	57.3%
			Damper Position "D"-824.1Ft.^{3}/Min. milligrams per Ft.^{3}-0.0895				
(1)	0.9150	0.8980	126	65	2754	1447	47.5%
(2)	0.9550	1.0703	135	67	2827	1252	55.7%
						Average =	51.6%
			Damper Position "E"-1091.2Ft.^{3}/Min. milligrams per Ft.^{3}-0.0676				
(1)	0.9020	0.8980	112	89	2483	1982	20.2%
(2)	0.9625	0.9432	116	80	2410	1696	29.6%
						Average =	24.9%